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ABSTRACT

This paper defines the structure of a semantic network for use in representing discourse and lexical meanings. The structure is designed to represent underlying semantic meanings that, with a lexicon and a grammar, can generate natural-language sentences in a linguistically justifiable manner. The semantics of natural English can be defined as a system of conditions and transformations applied to syntactic constituents to map them into semantic structures. A semantic structure for a statement is defined as a system of unambiguous representations of meaning interconnected by defined logical relations. The author feels that a semantic representation should probably be completely free of its natural-language representation. The correspondence between semantic structure and natural-language representation should reside wholly in the grammar and the lexicon. Specific details and examples of the semantic network operation are described. Illustrations of lexical structures are provided, and references are included. For additional information, see FL 002 345. (Author/VM)

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SOME SEMANTIC STRUCTURES FOR REPRESENTING ENGLISH MEANINGS

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R. F. Simmons

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ABSTRACT

A structure for semantic representation of English discourse and lexicon is described with some examples of semantic content representation for word, phrase, and discourse meanings. The semantic networks used are derived from those suggested earlier by Quillian, while the conventions for representing content are based partly on Fillmore's ideas of deep case structure. Attribute-value lists are shown to be a suitable linear notation for computational representation of networks. It is argued that the semantic network representation is a more convenient form for representing discourse meanings than the predicate calculus.

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RFS

SOME SEMANTIC STRUCTURES FOR REPRESENTING ENGLISH MEANINGS

R. F. Simmons

I. Introduction

The spoken or written representation of a discourse in English has the explicit structure of a string. That is, the discourse is a sequence of spoken or written symbols -- each symbol is followed by another symbol (including stops). Underlying this simple string structure however, there is a considerable depth of phonetic, morphological, syntactic, semantic and pragmatic structure that is implied by the sequence of choices of symbols.

More than half a century of linguistic study has developed a fair understanding of how to derive and represent phonemic, morphemic and syntactic structures implied by strings of natural language symbols -- not that there is complete agreement in the choice of any one system. It is only in recent years, however, that the semantic structures of natural languages have become an important topic of linguistic consideration. Definitions of semantic structures and means for deriving and representing them had a limited place in Chomsky's (1965) transformational theory, while in newer versions of the theory, (see Lakoff 1969) the underlying semantic structures of language become a basic component.

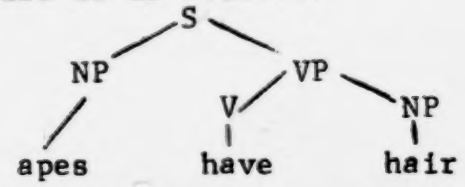
Developments of semantic notions with particular regard to formal languages had previously been the province of logicians such as Tarski (1944) and Carnap (1946). Their influence on linguistics can be seen particularly in terms of the methods and definitions of semantic analysis developed by Katz (1965), while in computational linguistics Thompson (1964) and Woods (1968) and others developed syntactic-semantic structures of natural language for question answering along lines suggested by these and other logicians. The way in which the levels of implicit structure of a natural language are obtained is outlined below.

The structures that are implicit in strings of linguistic symbols are made explicit with the aid of a lexicon and various grammars. Sequences of phonemes or graphemes are mapped by a system of rewrite rules into morphemes. Sequences of morpheme classes are mapped by a grammar of syntactic transformations into tree structures composed of syntactic constituents. Syntactic constituents are mapped by a system of selection conditions and transformations into a semantic structure that unambiguously represents certain aspects of their meaning. There probably exist pragmatic conditions and transformations that map semantic structures into actions.

The syntactic structure of a statement explicitly shows the syntactic relations and their ordering usually in a labelled tree structure, that is implied by a choice of symbols and their

ordering in a language string. The semantic analysis of the same statement is required to map the symbols into whatever represents their meanings in a given system, and to transform syntactically related constituents into logically related meanings. Thus, a semantic structure for a statement is defined as a system of unambiguous representations of meaning interconnected by defined logical relations.

In a trivial example, the sentence, "apes have hair", a syntactic structure is as follows:



One method of representing the semantic structure is as follows:

HASPART(a, b) & MNG(ape, a) & MNG(hair, b)

The semantic system is required to map the ambiguous symbols "ape" "hair" and "have" onto a, b and HASPART, respectively, as well as transforming from the syntactic tree structure into this logical form. The symbols a and b must refer to particular meanings and the relations HASPART and MNG (for Meaning) must be explicitly defined as logical predicates in order for the semantic system to be useful in explicating meanings that are implied by the statement.

The predicate, MNG(ape,a), implies all that is known about apes, e.g. SUBSET(a, animal), HASPART(a, legs), etc. One

semantic system is more powerful than another, to the extent that the first can obtain more implications than the second from a given statement. Two semantic systems can also differ in the type of inferences that they allow. One might be limited for some purpose to class membership and part-whole predicates, while another might be specialized to numerical and directional relations. These differences are frequently seen in the semantics of experimental question answering systems. (See Simmons 1970a).

One set of representation conventions -- i.e. syntax -- for semantic structure is given by various forms of predicate logic. Linguists such as McCawley (1968), Bach (1968), Lakoff (1969) have so far preferred this form. On the other hand computational linguists concerned with representing English textual meanings for question answering have often used attribute-value lists or semantic networks to represent semantic structure. These forms are alternate representational conventions, and the choice of conventions for semantic representation need have no relation to the resulting power of the system. A comparison of semantic network and predicate calculus representations is given in another paper (Simmons 1970b).

Because of the simplicity of its syntax leading to easier readability and computational convenience, I have chosen to represent English discourse meanings in semantic networks

closely related to those originally used by Quillian (1966), and further developed by Simmons et. al. (1968), Tesler et. al. (1968), Carbonnel (1970), Kay (1970) and others. This paper defines the structure of a semantic network for use in representing discourse and lexical meanings. It further attempts to develop a fragment of English semantics in showing some conventions for mapping certain syntactic constituents into semantic forms. Algorithms and transformational conventions for generating English sentences from such nets are the topic of another paper. (Simmons and Slocum 1970), and additional papers are in preparation showing applications of semantic nets to computer-aided instruction, and computational methods for translating from English strings to the networks.

II. A Semantic Structure for Discourse

The structure for representing natural language meanings that will be developed here owes much to Quillian's original work in defining a structure of semantic memory. Unlike his structure, this one is also linguistically motivated and indebted to discussions published by Fillmore (1968), McCawley, Bach and Lakoff. The structure is designed to conveniently represent underlying semantic meanings that, with a lexicon and a grammar, can generate natural language sentences in a linguistically justifiable manner.

In my opinion, a semantic representation should probably be completely free of its natural language representation. The correspondence between semantic structure and natural language representation should reside wholly in the grammar and lexicon. Such surface notions as tense and number, for example, should be represented semantically by relations such as Time of event and Quantity. The surface determiners, "a, an, the, some, all", and the null representation should be derived from values or interaction of values for Determination and Number relations in the semantic structure. The concepts which are the nodes of semantic structures should be representable by various lexical choices in such a manner that meaning preserving paraphrases will be a natural consequence of repeated generations of sentences

from the same semantic nets. Although these requirements are met in theory in this system, the reader will notice certain shortcomings in each of these areas, in the present development.

General Structure: The primitives of the system are taken as word-sense meanings for concepts, and discourse relations for semantic relations. A given word such as "pitcher" usually has more than one sense meaning, e.g. "a person who throws a ball" and "a container for pouring fluids". Each such sense meaning is a concept that will usually be represented by subscripting as, for example, "pitcher$_1$" and "pitcher$_2$". (Except, that an unsubscripted word-sense will imply the subscript "1"). A concept, though taken as a discourse primitive, is actually defined by lexical relations with other concepts thus forming its own concept structure as will be seen in a discussion of the lexicon in Section III.

A semantic structure is a labelled list of pairs where a label is a concept designator and a pair is composed of a relation and a concept. An abstract attribute value representation of a semantic structure is as follows:

$$\begin{array}{lll} C_i & R_a & C_j \\ & R_b & C_k \\ & .. & .. \\ & R_m & C_n \end{array}$$

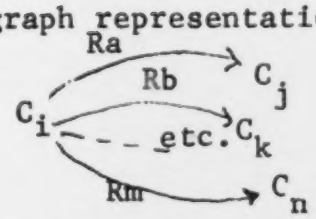
This list can also be represented as a set of triples as follows:

$$\begin{array}{lll} C_i & R_a & C_j \\ C_i & R_b & C_k \\ .. & .. & .. \\ C_i & R_m & C_n \end{array}$$

or as the set of predicates,

$$\begin{array}{ll} R_a & (C_i\ C_j) \\ R_b & (C_i\ C_k) \\ \vdots & \\ R_m & (C_i\ C_n) \end{array}$$

The corresponding graph representation is shown below:



The relations in semantic structures for representing discourse are comprised of deep-case names such as AGT, OBJ, INST, SOURCE, GOAL, THEME, DATIVE, etc., each dominating a preposition and another concept. In addition, the intersentential connectors such as "because", "therefore", "thus", "since", "before", "during", "after", etc. are assumed to be semantic relations in the network. Each relation is presumed to be definable in terms of inferences to be made strictly as a result of that relation. AGT(a,b) for example, implies that a is animate, that b is a process, and that a instigated b. DAT(a b) implies that a is an organism, b is a process, and that b has some effect on a. The case relations dominate prepositions which are also relational terms. For example, LOC may dominate a particular sense of "on", say ON7. LOC(a,b) implies that b has spatial coordinates and that these coordinates apply to the process symbolized by a, (where a may be a verb or a noun).

A more precise indication of how the spatial coordinates are to be applied is signified by the prepositional meaning that the case relation dominates. For the example of LOC dominating ON7, ON7(a,b) implies that a is in contact with b, a is above b, etc.

A similar situation applies to explicit sentential connectives. AFTER(a,b) implies that the event described by b occurs later than that of a. BECAUSE(a,b) means at least that the process of a occurs before that of b and that whenever a occurs, b must happen. THUS(a,b) means a implies b. Connectives like "however", "when", "whenever", etc., appear quite difficult to work out.

Determining precisely what is signified by each case relation, prepositional meaning and inter-sentential connector is a task of linguistic-logic definition that has hardly yet begun, but one which promises great rewards in showing how natural languages represent the depths of meaning implied by such simple statements as "the book is on the table". So, in saying that a semantic relation is "definable", what is meant is that such implications as the above examples can be derived as the meaning of the various relations. Once these are available, the semantic interpretation of a sentence is enriched by the explicit list of implications signified by such relations as AGT, OBJ, INST, LOC, TIM etc. and of the particular prepositional relations that they dominate. Such relations make clear and explicit the detailed features of interactions between pairs of concepts or processes in terms of space, time effect, affect, causality, etc.

The use of case relations as semantic connecting links derives partly from work by Fillmore (1968) who has shown that verbs may be considered as n-ary predicates with labelled case relations indicating the role of each nominal argument. In this development Fillmore has also argued that every noun in an English sentence is in a particular case relation to the verb that dominates it, and that the lexical structure for a verb must specify the case roles, prepositions and priority rules for surface ordering of its nominal arguments. In considering that semantic relations have explicit implications, I am following Woods (1968) and Raphael (1964) who demonstrated the computational efficacy of treating relational words as LISP functions or predicates. If a case relation is considered as a function (or subroutine), when it is called, it will return the list of implications relevant to that relation and its two concept arguments.

From a case grammar point of view, the semantic structure representing a sentence is essentially a verb sense-meaning in case relations to its nominal arguments. The notion of TOKen is introduced to indicate that a particular concept -- i.e. wordsense reference -- represents a particular occurrence of that concept, limited by the choice of context. Thus, there is some set of "breakings" such that John did them, or Mary; that were done with hammers, with axes, with automobiles; that happened

to various objects, at various times in various places. A particular "breaking" event -- or notion or concept or process -- is more or less precisely specified by the choice of its arguments. The semantic relation TOK(a,b) signifies that the event represented by a is a specified subclass of all the events signified by b. A subclass of "breakings" is specified in the following semantic structure for Fillmore's example sentence, "John broke the window with a hammer."

C1	TOK	break
	TIME	PAST
	AGENT	C2
	OBJECT	C3
	INST	C4
C2	TOK	John
	NBR	SING
	DET	DEF
C3	TOK	window
	NBR	SING
	DET	DEF
C4	TOK	hammer
	NBR	SING
	DET	INDEF

As in the use with "break", TOK(C3,window), signifies that subset of the concepts labelled "window" DETermined by the definite article in this context, and, TOK(C4,hammer) is an indefinite member of the set of ideas that "hammer" refers to. If we suppose for the moment that the listener or reader is familiar with this particular event of breaking a window, he might be

able to further specify "the window" as the "picture window in the house on Main Street", and the hammer as some particular entity as well. In an adequate communication procedure, the speaker has specified the particular event of "breaking" just well enough for the listener to identify exactly one of the many "breakings" he has remembered and the detailed conditions surrounding it.

Since each concept may be specified with numerous relations to other concepts, we need the indirection of reference exemplified in the concept name C3 referring to a particular token of "window" which is further specified by other relations of C3 to other concepts.

As the discourse is expanded with additional sentences such as, "Its glass shattered, cutting his hand" the tree structure of the initial representation generalizes to a network in which "its" refers to C3 and "his" refers to C2. Other interconnections will become apparent later.

Representing English Content in Nets: The preceding example illustrated the manner in which verbs and nouns are represented in semantic networks, following case grammar ideas developed by Fillmore. The situation with modifiers, conjunctions, the various uses of "to be", "to have", etc. has not been as well worked out by linguists. Consequently the conventions suggested in this section are first approximations that are seeking correction

and improvement.

1. Adjectival Modification: The semantic structure for adjectival modification must somehow take into account the relativity that this relation signifies. The phrases "small elephant" and "large ant" might be represented as the intersection of large things and ants, and of small things and elephants. If this approach were to be chosen, the relation SETX might be defined as that form of intersection. This is intuitively unsatisfying in that it simply ignores the relativity of the terms.

If we consider that SIZE is an attribute of physical objects such that each object has as a size value an appropriate range, then the relation SIZE(large, ant) would select the upper range of values for ants. In a similar fashion, COLOR(red, hair) and COLOR(red, firetruck) would select different values of the color, red. From a set theoretic viewpoint, the intersection of large things and ants, or red things and hair is still being accomplished, but the second approach assumes that the noun already specifies a subset of each relevant attribute such as size, shape, color etc. in the form of a range of measures. Recent psycholinguistic research reported by Olson (1970) supports this relative approach to adjectives.

The meaning of comparatives and superlatives as Celce (1970) is developing it, also depends on such a relativistic approach to adjectives. The sentence, "John is taller than Mary" resolves

to a logical structure such as the following:

GREATER(SIZE(tall,John), SIZE(tall,Mary))

This indicates that the SIZE measure associated with John is greater than that associated with Mary. Even such near-anomalies as: "the beer is colder than the coffee is hot" can be understood in terms of a relation that might be called GREATERDEV in the following:

GREATERDEV(TEMP(cold,beer),TEMP(hot,coffee))

This means the temperature of the beer deviates more from the average of beer in the cold direction than that of the coffee in the hot direction. This suggests that the measures might generally be in terms of deviations from averages. A sentence such as "The firetruck is redder than Mary's hair" suggests sets of ranges for each of the acceptable colors for firetrucks and hair.

In the semantic nets, the relation MOD is used to mean this relativistic interpretation of adjective meanings. MOD(large ant) is a relation that can eventually be defined as implying SIZE(large,ant), which in its turn can eventually be defined as a function that returns a measure in terms of average deviation units appropriate to its arguments. The comparative relation is signified in the network as GR for GREATER and it must have two arguments. In a sentence like: "John is taller, now", we must obtain the structure GR(MOD(tall, TIM(pres,John)), MOD(tail, TIM(past,John))).

2. Essive Relations: Four uses of the verb "to be" are considered. These are typified by the following examples:

E1 The ape is happy.

E2 The ape is an animal.

E3 That ape is the animal.

E4 The ape is in the tree.

In E1, there is simply an alternate form of the modification relation relationally represented by MOD(happy,ape) implying a positive measure on the ape's mood attribute. In semantic net form this would be shown approximately as follows: (without back references or determiners)

E1	C1	TOK	ape
		MOD	C2
C2		TOK	happy

Example E2 signifies the selection of a class of animals to be called apes. The cues that signify this usage are the choice of determiners showing that in the class of processes called animals, there is a subset named apes. Relationally this is signified by SETX(ape, animal). In a semantic net it is shown as follows:

E2	C1	TOK	ape
		NBR	Sing
		DET	Def
		SEXT	C2
C2		TOK	animal
		NBR	sing
		DET	indef

The next case, E3, signifies an identity of two classes each containing a single member. It is signified relationally by SETID(ape, animal) and the relation SETID is used in the semantic net.

Example E4, "the ape is in the tree" is often seen in its transformational embedding as "...the ape in the tree". Relationally, both are expressed simply as IN(ape,tree). For semantic networks, it is expressed as follows:

E4	C1	TOK	ape
		LOC	C2
C2		TOK	in
		-LOC	C1
		POBJ	C3
C3		TOK	tree

This practice is equivalent to a relational representation such as the following:

LOC(ape, IN(ape, tree))

By introducing a case relation, the treatment of prepositions in modifying nouns becomes similar in form to their treatment as arguments of verbs.

3. The verb "have": This verb is understood in the following two senses:

E5 John has hair.

E6 John has money.

These two senses represent the HASPART and POSSession relations, respectively. Relationally, they appear as follows:

HASPART(John , hair)

POSS(John,money)

They are represented in semantic networks as follows:

E5	C1	TOK	John
		HASPART	C2
C2		TOK	hair

E6	C1	TOK	John
		POSS	C2
C2		TOK	money

The determination of which meaning is signified by the context can be accomplished with the aid of semantic markers and selection restrictions following Katz (1965). The apostrophe as in "John's hair" or "John's money" is the usual form of transformational embedding seen in discourse and is treated in the same fashion as the full sentence.

4. Conjunctions: The conjunctions "and" and "or" are treated identically as indirect references in semantic nets, while "but" is considered to be an intersentential connective. In a sentence such as "John and Mary ran", the relational structure might be expressed as follows:

AGT(run, AND(John, Mary))

The semantic net shows this as follows:

C1	TOK	run
	AGT	C2
C2	TOK	and
	1st	C3
	2nd	C4
C3	TOK	John
C4	TOK	Mary

The relations "1st" "2nd", etc. are arbitrary designators to separate the references to the arguments. The indirect reference of AGT to its arguments through the separating switch,"and" is necessary to allow each member of the conjunction to be separately modified as in "the spotted dog and the striped cat ran".

At first glance this treatment appears to be different from the usual deep structure approach which would represent two deep structure sentences as "John ran" and "Mary ran". Separating the elements of a conjunction with the indirection of an "and" and its series of arguments, serves the same purpose by indicating that the relation AGT applies separately to each of the series.

Although the manner of signifying "or" is the same as that for "and", the meaning is obviously different in ways that will prove significant in attempting to apply paraphrase transformations to the structures. The effects of this difference are discussed in another paper (Simmons & Slocum 1970).

5. Adverbs: Two major classes of adverbs are shown in the following examples:

E7) John often/frequently ran to school.

E8) John reluctantly ran to school.

Sentence E8 allows the paraphrase, "John was reluctant in his running to school", while E7 does not allow, "John was often/frequent in his running to school". One would be tempted to suppose that adverbs act on verbs in a manner analogous to the way adjectives do on nouns. Thus the attribute "Frequency" might be supposed to characterize a verb, and an adverb such as "often" might select a particular range of frequencies in the same manner that "large" selects from a noun's range of sizes. The manner class of adverbs, however, seem to be related in some fashion to the subject noun and "reluctantly" refers not only to the process, "running" but specifically to "John's manner of running".

Lacking any deep understanding of adverbs, I have chosen to represent them in semantic nets with the relation VMOD, which is taken in analogy to the adjectival relation, MOD. Thus the relational form,

VMOD(run, often)

is expected to imply,

FREQUENCY(run, often)

and to lend itself to the same relativistic interpretation that was used with adjectives. The similarity of comparative constructions between adverbs and adjectives may offer some support for this treatment.

For examples:

E9) He ran more reluctantly than John.

E10) He was more reluctant than John.

E11) He ran more often than John.

6. Embedded Clauses: Deep structure sentences signified by adjectival modification, prepositional phrases, apostrophes, and conjunctions have been treated in previous subsections. This section considers relativization, some adverbial clauses and apposition as exemplified below:

E12) The man who caught the fish ate it.

E13) Before the man ate the fish, he caught it.

E14) Jones, the mayor, caught the fish.

The three examples are represented by the networks of Table 1.* In example E12 of Table 1, it can be seen that C2 (man) is the agent of both C1 and C4. This fact is reflected in C2 by the relation "-AGT" to C1 and C4. Similarly, C3 (fish) is the object of C1 and C4.

In a simple sentence, "the man caught the fish", both man and fish would have a single backlink-- -AGT and -OBJ respectively-- to the verb structure for "catch". The presence of more than one backlink signifies some sort of embedding. In generating a sentence from a semantic structure, the recognition of additional backlinks offers an opportunity to embed a sentence modifying the structure in which it occurs. If we begin to generate from C4 (catch), we could produce the sentence, "The man who ate the fish caught it" which is not quite the same as E13. This is possible because both verbs

*Nothing is said here of the complexities of Voice, Mood, Tense, Aspect, Form, Mode etc. A syntactic treatment of their use in semantically controlled generation is given in Simmons and Slocum (1970).

E 12

C1	TOK	eat
	TIM	Past
	AGT	C2
	OBJ	C3
C2	TOK	man
	NBR	sing
	DET	Def
	-AGT	C1,C4
C3	TOK	fish
	NBR	sing
	DET	Def
	-OBJ	C1,C4
C4	TOK	catch
	TIM	Past
	AGT	C2
	OBJ	C3

E 13

C1	TOK	catch
	TIM	Past(0,1)
	AGT	C2
	OBJ	C3
C2	TOK	man
	NBR	sing
	DET	Def
	-AGT	C1,C4
C3	TOK	fish
	NBR	sing
	DET	Def
	-OBJ	C1,C4
C4	TOK	eat
	TIM	Past(2,3)
	AGT	C2
	OBJ	C3

E 14

C1	TOK	catch
	TIM	Past
	AGT	C2
	OBJ	C4
C2	TOK	Jones
	NBR	sing
	DET	null
	SETID	C3
	-AGT	C1
C3	TOK	mayor
	NBR	sing
	DET	Def
	-SETID	C2
C4	TOK	fish
	NBR	sing
	DET	Def
	-OBJ	C1

Table 1 Semantic Networks for Three Sentences

are simply marked "TIM Past" and no importance seems to be attached to the order of the events described.

In E13, however, the situation is different in that the "catching" is marked as prior to the "eating" by the two-tuple value (0, 1) in contrast to the the value (2, 3) on "eat". These numbers mean that the "catching" started at relative time 0, and was completed by time 1; and the eating occurred between times 2 and 3. Respecting these time values and explicitly representing them, we can generate:

E'13 After the man caught the fish, he ate it.

E''13 The man caught the fish before he ate it.

etc.

The structure representing E14 shows that C2 (Jones) has only one backlink, "-AGT to C1 (catch)" but has the relation SETID connecting it to C3 (mayor). The relation SETID -- for set equivalence-- signifies that "Jones" and "the mayor" represent the identical concept. With this embedding relation we might generate the equivalent sentence:

D'14) Jones who is the mayor caught the fish.

The relation SETID is the signal of an embedded sentence and it is associated with transformations that allow the generation of either a relative clause or an apposition.

The relation MOD is treated in a similar fashion. Suppose in E14 of Table 1, that C4 (fish) had the relation "MOD C5 (old)". This would represent the deep structure sentence. "The fish is old" which could be generated either as an adjectival embedding, "old fish", or as a relative clause, "the fish that is old".

7. Determiner and Number: Two relations that have not so far been discussed, DET and NBR, also occur in Table 1. Values of DETerminer may be definite, indefinite and such words as"each," "every,""some," "all" etc. The values for NBR are Singular, Plural and Indeterminate. The effect of these relations is to specify or determine some subset of the events, processes or concepts named by a noun phrase. The complex manner in which they accomplish this feat has been the subject of numerous linguistic discussions summarized in Collinson (1937). For the present purpose it is sufficient to sketchily describe their effect in selecting -- i.e. quantifying -- a subset of the concept named by a noun phrase. The following list of examples and their relational equivalents are considered:

P1	some cup	Det(some, cup, Sing)
P2	some cups	Det(some, cup, Pl)
P3	every cup	Det(every, cup, Sing)
P4	all cups	Det(all, cup, Pl)
P5	a cup	Det(indef, cup, sing)
P6	the cup	Det(Def,cup,Sing)
P7	the cups	Det(Def, cup, Pl)
P8	no cup	Det(Neg, cup, Sing)
P9	no cups	Det(Neg, cup, Pl)
P10	some fish	Det(some, fish, Ind)

Examples P1 and P5 select any single event named "cup". P2 is an arbitrary selection of some subset of 2 or more cups. P10, in contrast, is ambiguous in that the NBR value of "fish" is indeterminate. P10 may indicate some one fish, some set of two or more fish, or some portion of one or more fish. P3 and

P4 each specify the entire set but P3 considers the set one-by-one, while P4 takes the set as a class. P8 and P9 are the exact converses of P3 and P4. Finally P6 and P7 select a particular set of cups, P6 signifying a set of only one member or occasionally acting like the null determiner, indicating the class "cups". In order to discover the particular set specified by P6 and P7, further information is required from the context.

The purpose of this discussion of Determination and Number is only to show that the function of these relations is similar to that of all other semantic relations--to specify some subset of the event or process being described. Their difference from other means of specification is to be found in terms of their logical inter-relations, which as logicians have shown with respect to logical quantifiers, is a regular system that is often required for generating equivalent paraphrases.

III LEXICAL STRUCTURES

In section II it was stated that word-sense meanings and semantic relations were the primitives of this semantic system. The lexicon is an inventory of the word-sense meanings available to the system. One of the tasks of a semantic analysis is to select a particular word-sense as the meaning of each word that occurs in a discourse string. The lexicon associates with each word and word-sense entry, the morphological, syntactic and semantic information required for this purpose. It also contains whatever additional information a particular semantic system requires in order to make explicit the meanings that are implied by the choice of words in the string.

Lexical structures are represented as a subset of the semantic network in exactly the same form as discourse nets. In this section they will be abstractly symbolized as a subscripted L-node associated with a list of attribute-value pairs, R_i-V_i, as follows:

$$\begin{array}{lll} L_i & R_a & V_j \\ & R_b & V_k \\ & \ldots & \ldots \\ & R_m & V_n \end{array}$$

V_i may refer to a constant, a lexical node, a discourse node or an implicational structure. Discourse structures are directly related to lexical structures by the relation TOK. The relational representation:

TOK(C1,catch)

that has been used previously is more accurately represented as:

TOK(C1,L82)

where L82 is the lexical entry for the particular word-sense of catch1. Thus the relation,TOK, connects an element of discourse with the word-sense concept to which it refers. The word-sense entry is defined in terms of syntactic features, semantic markers, selection restrictions, hyponyms, antonyms, and verbal and/or implicational definitions as required by the function of a particular semantic system.

Needless to say, the conventions developed in this section for representing lexical content are still highly tentative and are presented more for the sake of stimulating alternate considerations than for defining a semantics of the lexicon. Thus this section is to be taken as suggestive rather than definitive.

General Entry Form:

There are two types of lexical nodes; words and word senses. A word node has the relations WDSN, PI, PIN, PIV, PIADV, PIADJ. The value of WDSN is a list of word-sense nodes. The other relations indicate the Print Images for printing the word. PI refers to the standard form; PIN, PIV, PADV, and PADJ indicate variations, respectively as a noun, a verb, an adverb, or an adjective. A word-sense node has an arbitrary number of relation-value pairs that must include -WDSN the inverse relation referring back to the parent word node, -TOK whose value is a list of the discourse structures in a TOK relation to that word sense, and WC whose value is the syntactic word-class of that sense. Additional relations are such syntactic and semantic features as Gender, Mass-Count, HYPonym, ANTonym, Selection Restrictions, DEFinition etc. as required by various syntactic and semantic operations.

Figure 6 shows a fragmentary example of a lexical structure for the word "break" to illustrate the form of the structure and some of the relations. The actual content of a lexical structure will depend on the purpose of a semantic system that uses it.

In this figure we can see that the word has noun and verb print forms that are identical, that it has an adjective form that is the past participle of the verb, and no adverbial form. This is in contrast to a word such as "relate" whose noun form, PIN, would have the value "-ion" and whose adjective form, PADJ, might have the value "-or". The various print images of a word encode aspects of the morphological structure primarily at the word level. Assuming that the lexicon is alphabetically ordered by print form, the word, "broke" is entry L90 which refers to "break" at L75 with the inflection "PAST". At L75, the PIV relation lists the present, past and past participle forms for "break" as a verb. The entry L90 for "broke" also refers directly to the relevant word-sense entry, L77, (and any other verb senses) eliminating consideration of sense L76, a noun sense. Additional discussion of morphological considerations in semantic nets can be found in Kay (1970) and Chapin and Norton (1968). It is assumed in this discussion, that the procedure for looking up words in a lexicon includes at least such morphological analysis functions as detecting regular inflections on words. Thus to look up "related", the morphological routines would analyze the word into "relate + PAST", and find the lexical entry for that form.

The example word-sense L77 for "break" also illustrates the conventions for identifying the arguments associated with the case relations "AGT", "INST", and "OBJ". The value for the Agent relation is limited to concepts marked as (i.e. with HYP values of) "animate" or "organism". The object relation, is marked as <u>required</u> (by the code +) and limited to concepts marked "physical object" and the relation "with" is limited to concepts marked "instrument" or "physical object". Since only the object relation is marked as <u>required</u>, the agent and instrument are taken as optional. The entry thus indicates that sentences such as the following are well-formed:

```
L75     WDSN    (L76 L77)
        PI      BREAK
        PIN     PI
        PIV     PI,BROKE, BROKEN
        PADJ    P PART

L76     WC      Noun
        PL      S
        GDR     N
        TYPE    Count
        DEF     (C21)
       -TOK     (C21 C52 ...)
       -WDSN    L75
        HYP     (SEPARATION, STATE)

L77     WC      V
        PAST    BROKE
        PPART   BROKEN
        3PS     S
        AGT     (ANIMATE, ORGANISM)
        OBJ     (+, physical object)
        INST    (INSTRUMENT, PHYSOBJ)
        HYP     (SEPARATE, DIVIDE, DESTROY)
        DEF     C145
       -TOK     (C145...)
       -WDSN    L75

L90     WDSN    L77
        PI      BROKE
        PIV     L75,PAST

L95     WDSN    L77
        PI      BROKEN
        PIV     L75, PPART
```

Fig. 6 Illustration of Lexical Structure

1) John broke the window with a hammer.

2) John broke the window.

3) The hammer broke the window.

4) The window broke.

and sentences such as these (as partial paraphrases of 1) are not:

*5) John broke.

*6) A hammer broke.

*7) John broke with a hammer.

This appears to be a satisfactory method for distinguishing required and optional arguments for verbs.

The semantic restrictions on the arguments follow Katz's (1965) system of selection restrictions. Restrictions such as "animate" and "organism" require that whatever noun phrase is the value of the argument "AGT" must have as one of the values of the HYP (HYPonym or Semantic Marker) relation exactly the marker "animate" or "organism". Thus if "John" has the markers "human", "organism" and "animate" while "hammer" has the list "instrument", "physical object", it can be seen that "John" can be in the AGT relation while "hammer" can be taken only in the INST or OBJ relations. If "window" is not characterized as "instrument" then it can only be taken in the object relation and the arguments of sentences 1, 2 and 3 can be correctly distinguished. In passing, it should be noted that the relation HYP is transitive. Thus if "John" has the HYP value "boy" which has the HYP value "male", "John" is also "male".

Although this Katzian approach to selecting word-senses and sorting arguments can be shown to work for simple texts, it is apparent that additional semantic apparatus--still undiscovered--will be required for dealing with even such simples cases of metaphor as "John broke up the meeting with a joke".

The values of the DEF argument in L76 and L77 respectively are references to C121 and C145 whose content would be the discourse encoding of the following definitions:

C121 Space between two places or times

C145 Make into separate parts by force

It is probably these values that will eventually prove most useful for semantic analysis following methods suggested by Sparck-Jones (1965) and Quillian (1966) but so far not worked out in an adequate fashion.

Prepositions:

An additional relation ENTail characterizes many sense meanings. ENT relates a word-sense to any implicational rules that refer to it. The definition of these rules and their use, although touched lightly in the following discussion of prepositions, it is considered sufficiently important to warrant a section of its own following this one.

Some idea of the lexical structure for prepositional meanings is given by the examples of Figure 7. In this figure lexical structures for four of several meanings for the word "on" are outlined. The senses illustrated are taken from examples studied by White (1964) in the following abbreviated contexts:

L5) move on wires
keys on the keyboard
man on the street
ports on the coast

L6) hear on the radio
talk on the telephone
see on television

L7) spend on advertising
wasted on building

L8) push on pedal
march on Rome
force demands on people

The relations, HD and P OBJ are reserved for prepositional meanings and refer to the syntactic head and object of the preposition. Thus, for "move on wires", "move" is in the HD relation, and "wires" is in the OBJ relation to the preposition "on". In the discourse nets, the relation HD refers to that wordsense that dominates the Case Relation

```
L4      PI      ON
        WDSN    (L5, L6, L7, L8...,

L5      W/C     PREP
        HD      (PHYS OBJ, ACTION)
        P OBJ   (PHYS OBJ)
        HYP     LOCATIVE
        IMPLY   (I25, 26...)
        -WDSN   L4

L6      W/C     PREP
        HD      (Communicate)
        P OBJ   (Instrument)
        HYP     INSTRUMENT
        IMPLY   (I72, 73...)
        -WDSN   L4

L7      W/C     PREP
        HD      (Expend)
        P OBJ   (Purpose)
        HYP      Goal
        IMPLY   (I35, 36...)
        -WDSN   L4

L8      W/C     PREP
        HD      (Causal act)
        P OBJ   (PHYS OBJ, PLACE)
        IMPLY   (I35, 42...)
        -WDSN   L4
```

Fig. 7 Lexical Structures for Prepositional Meanings

that dominates the prepositional phrase. In reference to a syntactic constituent, HD refers to the noun or verb that dominates a prepositional phrase.

These relations in the word-sense entry have as values selection restrictions on the concepts that can be taken as HD and OBJ arguments. The relation HYP indicates the hyponym or semantic marker that characterizes the meaning. The values of HYP in prepositional meanings are usually Case relations or other prepositional meanings. The relation IMPLY has a list of implication statements as values. Thus for L5, the locative sense of "on", I25 and I26 might have the following structures:

I25	TOK	touch
	DAT	HD
	OBJ	OBJ
I26	TOK	above
	HD	HD
	OBJ	OBJ

It is intended that the meaning of each prepositional sense will be defined primarily by the implicational structures associated with it. To actually accomplish this for any number of prepositional meanings is a large task that has been studied to some extent by White (1964), and Glasersfeld (1965). In each case a few dozen prepositional meanings have been identified by context and specified as some combination of more elementary relations.

A similar form probably encompasses intersentential connectives such as "because", "since", "before", "if", etc., but examples of their content have not yet been studied in any depth.

Since the meaning of a prepositional word-sense is seen as primarily relational, no use has so far been found for a DEF relation with a verbal definition as its value. The relation -TOK is also not illustrated although it can be included if lists of contexts are desired for the study of prepositional meanings.

Lexical structures for adjectives include selection restrictions on their noun head and the noun must eventually include sufficient relational structure to account for the relativity of such meanings as "large ant", "small elephant", oldest youth", etc. Conjunctions require agreement in syntactic class and semantic features among

their arguments; pronouns specify agreement with their referent in terms of NBR, Gender, and Case; and function adverbs must also specify the nature of their arguments in their lexical structure. Most of this type of content structure is still to be worked out.

IV. Implicational Structure:

Several authors (notably Lyons (1968), Woods (1968) and Fillmore (1968)) have attempted to explicate notions of implication, entailment, presupposition, etc. with regard for English word meanings. They have successfully demonstrated the importance of implicational structure as a part of the meanings. In this section, a semantic network and some examples of content are described to represent some of the implicational structure of sense meanings.

The simplest level of implicational structure occurs in the relations HYP and DEF. Generally, if a word-sense is used in a sentence or question, its hyponym or its definition can be substituted without changing its truth value. Thus if "a man ate a fish" is a true statement, the substitution of hyponyms and definitions results in another pair of true statements: "a human ingested an animal", and "a male adult human took in through his mouth as food an aquatic animal". This kind of substitution can be repeated to result in increasingly abstract statements on the hyponym level, and ever more detailed specifications of word meaning at the definitional level. Question-answering research uses this technique as its first level of inference. (See Simmons et. al. (1968) & Schwarcz et. al. (1970)). It has probably been noticed that there is no explicit synonym relation in the lexical structure. This relation is accounted for by a word-sense mapping onto two or more different words that in their various contexts can refer to the same meaning. Thus it is expected that such words as "get" and "receive" would share a word-sense which in its turn would relate by the -WDSN back to the two print forms.

Another common form of inferential structure is the converse relation that holds between such pairs as "buy-sell", "like-please" as illustrated in the following examples:

2a) John liked the play.

2b) The play pleased John.

3a) John sold the boat to Mary.

3b) Mary bought the boat from John.

These pairs of sentences are not considered to have the same semantic structure in this system in that they differ in terms of choice of verb token and in terms of case roles for the nouns. (For some purposes other semantic systems might choose to represent both members of the pairs identically as some deeper semantic structure such as "an exchange from John to Mary for value".) In each pair, the b sentence is related to the a sentence by a transformation on the semantic structure as shown in Figure 8. The lexical entries for "like" and "please" each refer to the converse transformations by the relations ENT; and E1 and E2 can be seen to refer back to these lexical entries by the relation -ENT.

An Implication transformation is represented in the same net form as any other semantic structure with the exception that V_i, the symbol for a variable, is allowed as an argument for relations. Implicational structures are characterized as numbered E-nodes associated with appropriate relations and their values. Every E-structure will have the relations -ENT and IMPLY as relations.

If it is desired to transform 2a into 2b, the lexical entry for "like" will have an ENT relation whose values will include E1. A straightforward algorithm is used to bind the variables, V1, V2, and V3 to the appropriate arguments of the semantic structure to be transformed and to rewrite the structure into the form that is the value of the IMPLY relation. Thus, applying E1 to the discourse structure that represents "John liked the play", is illustrated as follows:

```
C1   TOK   like
     T     past
     DAT   C2...(John)
     OBJ   C3...(the play)
```

Further development of C2 and C3 are indicated in parentheses. In applying E1 to this structure, V1 is bound to C2, and V2 to C3. E1 and E2 now take on the following values:

```
1)          E1      -ENT    like
                     DAT    V1
                     OBJ    V2
                    IMPLY   E2

            E2      -ENT    PLEASE
                     OBJ    V2
                     DAT    V1
                    IMPLY   E1


2)          E3      -ENT    SELL
                     AGT    V1
                     OBJ    V2
                    GOAL    V3
                    IMPLY   E4

            E4      -ENT    BUY
                     AGT    V3
                     OBJ    V2
                  SOURCE    V1
                    IMPLY   E3
```

Fig. 8 Converse Implicational Structures
for "like-please", "buy-sell"

E1	-ENT	like
	DAT	C2
	OBJ	C3
	IMPLY	E2
E2	-ENT	please
	OBJ	C3
	DAT	C2
	IMPLY	E1

C1 is now rewritten (by an IMPLY function) in the form of E2 to give:

C'1	TOK	please
	T	past
	DAT	C3...(the play)
	OBJ	C2...(John)

The pair, T-past, was not involved in the transformation so it was merely copied unchanged.

A sentence generator applied to C'1 will now generate "the play pleased John". The "buy-sell" transformation operates in a similar fashion with three arguments. It can be seen that the converse transformations are bi-implicational in that each verb meaning implies the other. For other types of implication exemplified by the pair:

4a) John killed Jim,

4b) Jim died,

sentence 4a) implies 4b) but 4b) does not imply 4a). Consequently, the E-structure referred to by "kill" implies "die" but not conversely, as shown below:

E5	-ENT	kill
	AGT	V1
	DAT	V2
	IMPLY	E6
E6	-ENT	die
	DAT	V2
	-IMPLY	E5

Complex Relations:

More complex relations such as complex products, can be represented in a similar fashion. Consider the complex product of "lead" and "lose" (from Schwarcz et.al.(1970)) in the example pair:

5a) Napoleon led the army that lost the battle

5b) Napoleon lost the battle.

It is maintained that sentence 5b is implied or entailed by 5a in accordance with a complex product (with qualification to be mentioned

later) such that: (lead C/P lose) IMPLY lose. This rule can be represented in semantic net form in accordance with Figure 9. Figure 9a is a semantic representation of sentence 5a while 9b shows the simplest form of the C/P rule. By binding V1, V2 and V3 to C2, C3 and C5 respectively, the rule E10 generates the structure of sentence 5b.

Additional restraints are often required on the applicability of complex products. For example "the lieutenant led the platoon that lost the football game" does not strongly imply that the lieutenant lost the football game. To accomplish any degree of restriction, the rule of 9b can be further specified as in Figure 10, to limit the applicability of variables to lexical entries that have the features required. The use of the restriction requires a test of the proposed lexical entry, before binding it to the variable. Further extensions can be devised as needed for the complicated task of exploring the implicational relations of word meanings.

```
C1      TOK     lead
        T       PAST
        AGT     C2...(Napoleon)
        DAT     C3

C3      TOK     army
        NBR     sing
        DET     the
       -DAT     C1
       -DAT     C4

C4      TOK     lose
        T       past
        DAT     C3
        OBJ     C5...(battle)
```

9a) relevant sentence structure

```
E10     -ENT    lead,lose
         AND    (E11, E12)
        IMPLY   E13

E11     TOK     lead
        AGT     V1
        DAT     V2
       -AND     E10

E12     TOK     lose
        DAT     V2
        OBJ     V3
       -AND     E10

E13     TOK     lose
        DAT     V1
        OBJ     V3
       -IMPLY   E10
```

9b) complex product rule

Fig. 9 Example of Complex Product Implication

```
E10     TOK     C/P
        AND     E11, E12
        IMPLY   E13

E11     TOK     lead
        AGT     E14
        DAT     E15
       -AND     E10

E12     TOK     lose
        DAT     E15
        OBJ     E16
       -AND     E10

E13     TOK     lose
        DAT     E14
        OBJ     E16

E14     VAR     V1
       -HYP     leader
       -AGT     E11
       -DAT     E13

E15     VAR     V2
       -HYP     military group
       -DAT     E11

E16     VAR     V3
       -HYP     battle
       -OBJ     E12, E13
```

Fig. 10 Restricted Variables in Implication Rules

V DISCUSSION AND CONCLUSIONS

A network structure has been described to represent semantic forms and content of discourse, lexical entries and implicational rules. Conventions have been suggested for representing meaning content of natural language statements and lexicon in this form. The semantics of natural English has been defined as a system of conditions and transformations applied to syntactic constituents to map them into semantic structures. A semantic structure is a system of unambiguous representations of meanings inter-connected by logical relations. In this paper the discourse meanings have been taken as lexical word-senses and the logical relations are Fillmore's deep cases dominating prepositional meanings, such sentence connectives as "thus", "because", "before", etc. and certain other logical relations such as HASPART, SETX, etc.

It has been maintained that each semantic relation must be definable as a rule or function that takes a series of arguments and substitutes as its meaning another set of relations among the same or different meaning objects. Thus, part of the meaning of TOK(C1, CL5) is that additional relations on C1 include all of the lexical and implicational relations associated with L5, including of course its print image. AGT(C1, C5) indicates that the action or process C5 was initiated by the organism, C1, while DAT(C2,C5) indicates that C2 is an organism that was affected by C5. No complete inventory of semantic relations is yet available, and fully detailed definitions of those that have been recognized is still a matter for continued research of the type typified by Leech (1970), Fillmore (1968) and Woods (1968).

The pragmatics of a language utterance is the effect that it has on the behavior of the listener (Morris 1955). Some glimpse of a pragmatics of English is sensed in the implicational content associated with the lexical structure. If the system in question is one that tests truth values by comparing an input sentence such as "John liked the play" with one known to be true, as "The play pleased John",

then the pragmatic structure would be those inference structures used to map the semantic form of the first sentence into that of the second. In such a formulation, pragmatic structures for paraphrase, question answering and translation systems could each have similar forms, but widely differing content. Further investigation of this hypothesis is also a matter for the future.

The potential value of explicating semantic, lexical and implicational structures of natural language is amply demonstrated by the productive stimulation offered by recent work in linguistics and by the potential utility of computer-based language processing applications. This suggests that the detailed exploration and definition of these structures offers a highly rewarding research area for linguists whether their orientation is descriptive, structural or computational.

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